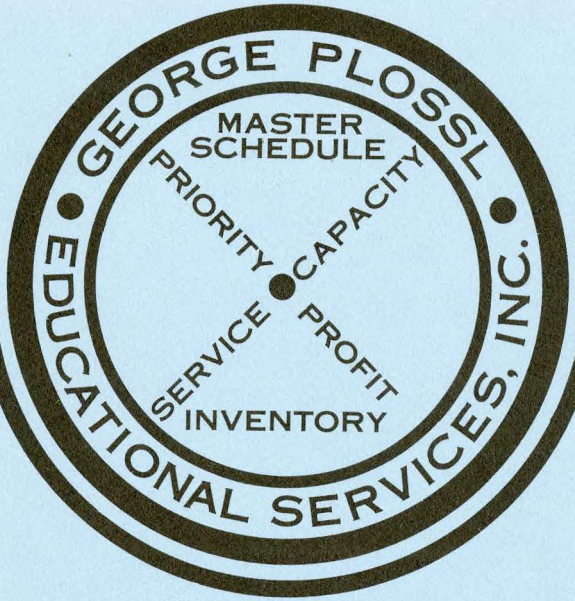

How Much Inventory Is Enough?

by George W. Plossl

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HOW MUCH INVENTORY IS ENOUGH?

How long has it been since a conversation like this occurred among your company's top management? The Controller usually opens the subject, stating forcefully, "We've just got to get some capital, and it's obvious that the best way is to cut inventories. Our turnover rates are lower than our competitors' anyhow.".

The Sales Manager, of course, has a different approach. "Don't think of cutting finished goods", he says. "We could increase our share of the market if we had more products regularly in stock. I think we ought to stock more specials, too".

The Plant Manager, thinking of raw material and work-in-progress, says, "If I'm going to keep costs down and profits up, I need more insurance against running out of raw material and purchased components. We've got some ideas on better tooling and equipment, too, but we'll need longer runs, which means more inventory".

By this time, the General Manager has heard enough of the same old arguments. "What I'd like to know," he says, "is ***how much inventory we really need*** to run this business?" As usual, his question is answered by a loud silence.

Is there a rational answer? Most companies seem to follow cycles. When management's attention is focused on the high cost of money, the answer is "Less" (how much less depends on the amount of capital needed or on some arbitrary target of turnover). When the need is to improve customer service by reducing backorders or adding warehouses, the answer is obviously "More" (hopefully not too much more). When costs come under close scrutiny, "More" seems necessary to take advantage of economical mass production manufacturing techniques (again with little understanding of how much more). Inventory is viewed with biased perspective, too frequently ***as a necessary evil.***

There's no doubt that the "right" total inventory will depend on management's goals for the key objectives of customer service and return on investment. What's missing in most companies, though, is a clear understanding of the relation between "return" and "investment" for inventories. Unfortunately, the standard, accepted cost-accounting methods of reporting inventory investment do nothing to clear up this misunderstanding. Without exception, these report total value of such classes as Raw Material, Purchased and Manufactured Components, Work-In-Process, Finished Product, Supplies and Miscellaneous.

Why these classifications? Obviously they are convenient for "scorekeeping"; it's easy for accountants to track the flow of value from one to another. What comes in from outside sources is raw material or purchased components. When work begins, these are transferred to work-in-process and labor and overheads are added. The result is finished product ready to ship to customers. The chain is completed by "accounts payable" and "accounts receivable". The supplies and miscellaneous classes are handy catchalls for items which cannot be identified with the product. Unhappily, these classifications contribute nothing to help managers answer the basic questions involved in controlling inventory,

How should inventory vary with changing sales?
What will happen to customer service and operating costs if inventories are changed?
How much inventory is enough?

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One Controller recently issued a policy letter stating, "From now on, inventories will vary directly with sales rates. An increase of 10% in shipments will justify a 10% increase in inventory and vice versa." It's easy to be sympathetic to the frustration which initiated this. Inventory investment had been out of control for years, steadily increasing, usually more rapidly when sales fell. However, while perhaps better than no policy, his left much to be desired. First, he implicitly accepted the present total as right. Second, he viewed inventory too narrowly as simply supporting sales; he ignored its effect on operating costs.

The most popular measure of effectiveness of control of inventory is "Turnover", usually expressed as the ratio of cost of goods sold in a period to the value of total inventory at the end of the period. Occasionally the reciprocal is used, expressing the inventory as a percentage of the total cost. Turnover has only one valid use - it is a ***good measure of trends.*** Attempting as some do to use it as an ordering control - "to get four turns you have to order three month's supply" - can be extremely costly; the obvious example is purchase discounts. Its most serious deficiency is that it gives no clue as to what is "par" for your business. Using other companies' data makes some basic assumptions which usually are not valid:

Products and processes are similar.
Policies on customer service, employment, distribution, product obsolescence, etc. are similar.
They're doing a good job of managing inventory.

Another common approach to setting inventory targets is based on "theoretical average inventory". When using an Order Point / Order Quantity system of ordering, a time diagram of inventory looks like Figure 1, the familiar saw-tooth pattern. Theoretically the average inventory will be one-half the order quantity, plus the safety stock, for each item so ordered.

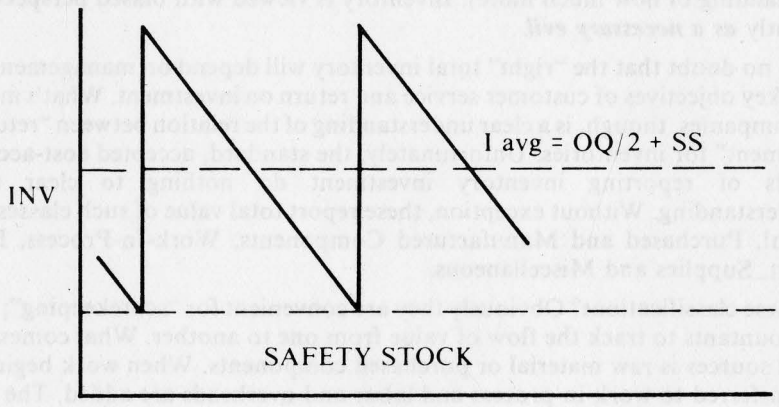

FIGURE 1

Companies using this approach invariably find actual inventories considerably higher than the calculated targets, because:

Usage is not uniform as the theory assumes, so the average is more than half the lot-size.

Parts are used in sets in assemblies, although the theory assumes each item is independent of others.

Material is ordered earlier than planned to "be safe" or to "keep the shop busy". Few companies actually follow their ordering rules.

Many classes of inventory are not included; among them are work-in-process, build-ups of seasonal items, obsolete parts, in-transit material, etc.

Purchase discounts generate excess inventory above the calculated order quantities.

Even when efforts are made to account for all classes, the first three factors cause large differences between target and actual inventories.

Another common method bases the target level on time cycles. The flow of material for each major product family from raw material through finished product inventories is charted and time cycles assigned to each phase. These are listed and the total value of material calculated as shown in Table 1, starting with finished goods and taking into consideration the value added in each phase. The total of these phase values is then divided by the "relief" rate (the rate of sales or shipments) to determine a weighted-average day's supply as the target. It is usually assumed that "standard" time-cycles apply equally well to all items in the product family and to various "relief" rates. The results hardly justify the added effort although the method does have the advantage of insuring that all phases of inventory are included.

TABLE 1

Target Standard Calculation

Production Line I:

Inventory Location	Planned Relief $/day	Standard Days	Standard $
Finished Goods	8,710	10	87,100
Assembly W.I.P.	8,710	1	8,710
Compon. Stores	8,260	10	82,600
Sub-assem. W.I.P.	8,260	1	8,260
Compon. Stores	6,460	10	64,600
Compon. W.I.P.	3,500	30	105,000
Raw Material	1,700	30	51,000
In Transit	1,500	10	15,000
		Standard $ Total	422,270
		Planned Finished Goods Relief	$8,710

Target Standard Inventory = 422,270/8,710 = 48-1/2 days.

Confusion and conflict will persist until we adopt a rational, professional view of inventories as ***assets, not liabilities.*** The present approach has failed because it obscures rather than clarifies the functions of inventories. They can and should earn a return on the investment just like plant, machinery, tooling and other physical assets. The basic problems are to ***determine how inventory earns a return and how much return is earned.***

The conventional approaches using accounting classifications, turnover rates, inventory percentages and the like cannot help solve these. Until they are, however, the relation of inventory to sales, the effect on costs and customer service and the "right" total will remain mysteries. What's needed is ***concentration on the functions inventory performs which yield measurable benefits.*** These are summarized in Table 2 for six classes of inventory and the benefits indicated.

TABLE 2

Function	Benefits
Lot-size (or order quantity)	
Uncouple manufacturing operations (i.e., screw-machines vs. assembly; supplier vs. user).	Purchased discounts; reduced setup, freight, material handling, paperwork & inspection expense, etc.
Demand-fluctuation (or safety stock)	
Insurance against unexpected demand (safety stock).	Increased sales; reduced outgoing freight, substitution of higher value product, customer service, clerical telephone & telegraph, packaging costs, etc.
Supply-fluctuation	
Insurance against interrupted supply (i.e., strikes, vendor lead time variations).	Reduced downtime and overtime, substitute materials, and incoming freight; increased sales.
Anticipation	
Level out production (i.e., to meet seasonal sales, marketing promotions).	Reduced overtime, sub-contract, hiring, layoff, unemployment insurance, training, scrap and rework expense, etc. Less excess capacity in equipment needed.
Transportation	
Fill distribution pipeline (i.e., in-transit, branch warehouse and consigned materials).	Increased sales; reduced freight, handling and packaging costs.
Hedge (or speculative)	
Provide hedge against price increases (i.e., copper, silver).	Lower material costs.

Obviously, these functional classes bear no relation to standard accounting groupings. Inventories of raw materials, finished components, work-in-process and finished products all could be carried to uncouple manufacturing operations, permitting them to run at the most economical rate and provide maximum utilization of equipment. Equally obviously, the specific "return" from only a few of the minor benefits can be found in the acounting records of most companies; typical of these are freight, clerical expense and overtime. The most important benefits, however, like increased sales, lower setup costs and reduced downtime, hiring and layoff expense have to be "engineered." The present accounting systems have been designed for the scorekeepers; they are of little use to the players.

Solution of the problem of "How much inventory is enough" begins by evaluating the benefits for each functional class of inventory in Table 2. Theoretical approaches are available for evaluating return on inventory investment for each.

LOT-SIZE INVENTORY (Finished parts in stock)

The theory of the "economic order quantity" has been very well covered in the literature. First published in 1915, (1) the formula balancing ordering costs with carrying costs to produce the lowest total has been apparently of more use to those

teaching and writing about inventory than to those attempting to control it. Based on our surveys of those attempting to apply the formula in the real world, seven or eight have serious problems for every one able to identify specific benefits. The basic problems have been identified: (2)

Inaccurate data are used for projected demand (forecasts), ordering costs (estimates) and, particularly, the cost of carrying inventory (guesses).

Attention is concentrated on each item with the impact on total costs and investment ignored.

Specific savings are not identified; the assumption is made that benefits will accrue automatically.

Objective is limited to achieving the minimum total of ordering and carrying costs.

Most of those applying EOQ formulas have been playing a game of "magic numbers" — doing their best to get the "right" numbers to put in the correct formula and expecting it to make the proper lot-size decision, subject only to some modifications for rounding off or avoiding ridiculous extremes. The first to suggest a departure from this stereotyped approach was W. Evert Welch (3) who recognized that very significant savings could be made by applying the theory of EOQ ***to "families" of items*** even without evaluating the cost factors in the formula. Where intuitive or "rule-of-thumb" methods have been in use, Welch showed how to reduce the lot-size inventory of a family of items while continuing to place the same number of orders, or to reduce the number of orders while holding the lot-size inventory constant. Using his method, Table 3 illustrates the potential benefits of applying the theory of EOQ to a family of three items previously ordered four times a year. Welch pointed out that his results were not the "most economical", just ***more economical than intuitive methods.***

TABLE 3

	Without EOQ Theory			With EOQ Theory			
				Lowest Inventory		Fewest Orders	
Item	Annual Usage	Orders Per Yr.	Order Size	Orders Per Yr.	Order Size	Orders Per Yr.	Order Size
A	$4,900	4	$1,225	7	$700	5.4	$904
B	900	4	225	3	300	2.3	388
C	400	4	100	2	200	1.6	258
Totals	$6,200	12	$1,550	12	$1,200	9.3	$1,550
Average Lot-Size Inventory =	$775				= $600		= $775

In a similar approach, Dr. S.B. Smith (4) showed how to force the EOQ formula to set lot-sizes for a family of items which would not exceed a restriction on the total capital available for this investment. He assumed that "economic orders" based on the formula were already being used but that the wrong carrying cost was employed. He showed how to calculate an "imputed" carrying cost which would achieve the desired percentage reduction in investment. Like Welch, Smith's concern was to get the maximum benefit from the theory for ***groups of items subject to real limitations.***

Several others about this time had begun to question the validity of the search for the "correct" carrying charge. R.L. VanDeMark (5) pointed out that changing the value assigned to the cost of carrying inventory would be a logical way to vary the total lot-size inventory as desired. R.G. Brown called this factor "a management policy

(1) All references are summarized on page 19

variable" (6) and also discussed using the carrying charge as a device to control total lot-size inventory and the expense associated with equipment setup. (7)

In 1963 a technique called LIMIT (Lot-Size Inventory Management Interpolation Technique) was developed (2) by which the relationship between investment in inventory and total ordering costs for large families of items could be presented in tabular form or as a "trade-off" curve, Figure 2.

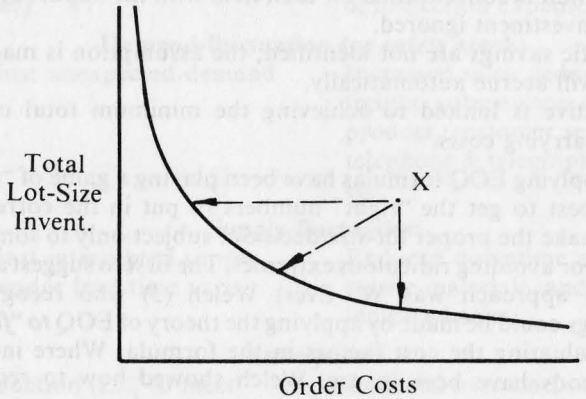

FIGURE 2

Intuitive or rule-of-thumb ordering result in inventory/cost relationships above the theoretical curve, like point "X" on Figure 2. ***The theory can then be used first to get down on the curve.*** Several alternatives are possible: hold costs the same and reduce inventory (move vertically); hold inventory constant and cut costs (move horizontally); or cut both inventory and costs (move diagonally). The real value of the technique is that it provides a management tool to determine when the further savings in ordering costs represent an inadequate return on the investment in additional inventory. ***It thus provides a rational way to set total lot-size inventory goals.***

Achieving these goals, however, will not be "automatic". If costs are to be reduced, ***specific actions must be identified and taken*** - setup men must be given additional work, clerks must be transferred, etc. The techniques show the potential savings — management must act to capture them. Even where the goal is reduced inventory, the ***formulas*** alone ***will not generate savings.*** Tompkins has shown (8) how just changing order quantities simply shifts total inventory between Lot-size and Fluctuation classes ***unless capacity is adjusted.***

Companies have used aggregate techniques in a variety of ways to achieve significant benefits in operation. Individual item order quantities can be set to insure a full work load and minimum total inventory for the actual number of setup men or order clerks working. They can also be calculated to insure that the total setup time on a critical machine (taking it out of production) does not cut into the minimum operating time needed to produce the required total output. In this situation, the techniques can also provide additional data to aid capital investment decisions by showing the potential reductions in inventory from adding equipment thus removing setup limitations and permitting smaller lot-sizes to be run.

Purchase discount decisions have suffered from the same "one-item-at-a-time" approach. The decision to take the discount or not is usually based on whether the savings from lower unit prices and fewer orders exceed the cost of carrying the additional inventory. The decision hinges on "knowing" the carrying cost and the

approach gives no indication of the total impact on capital investment of ***all*** discount decisions which might be taken. Viewing the net savings as return on investment and ranking a number of potential discounts in order of return on the added investment (9) would permit taking only those discounts which meet management's desired return similar to goals set for capital equipment. The objection is frequently raised that "we can't identify now all items we may be able to get discounts on". This is true, of course, but no excuse for not using the technique for all known discount situations, and making a real effort to be sure all "A" items (those with high usage-value) are covered. These will obviously generate the bulk of the return and are most likely to have discount possibilities.

LOT-SIZE INVENTORY (Work-in-process)

With minor exceptions, the bulk of work-in-process should be lot-size inventory.

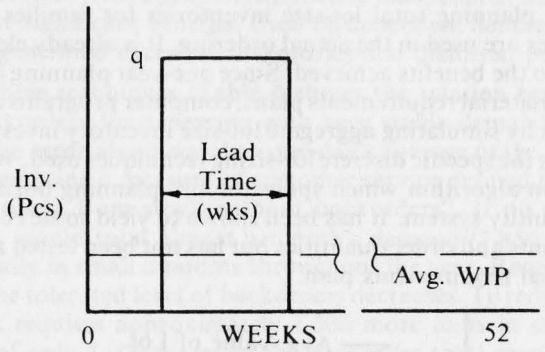

FIGURE 3

For castings being machined into finished parts, Figure 3 shows the lot quantity expressed in "pieces" and the lead time in "weeks" needed for all operations on each lot. Averaged over the year, this work-in-process will be q(LT/52) for each lot. The total number of lots, "n", run during the year will result in an average total work-in-process of nq(LT/52) for each item. Since "nq" is the total annual demand for the item, the ***average*** amount of pieces of work-in-process for each item will then be:

$$WIP_{avg} = \text{Actual Demand } (LT/52)$$

The interesting point is that the ***average work-in-process is not affected by the lot size;*** it is proportional to the annual demand and the lead time. This makes it simple to set target levels for work-in-process, if normal lead times are defined. It also demonstrates clearly the advantage of cutting lead times and reducing work-in-process in the plant, particularly for high-usage items.

Working with dollars and real inventories, scrap, rework, material costs, labor and overhead must be introduced. Increasing lot-sizes to make provision for scrap losses will increase the average value of work-in-process. Rework will also increase it by the longer time and additional labor required. The average ***value*** of a lot depends on how material and labor are added as the lot is processed. When the bulk of the labor is performed in the first few operations as shown in Figure 4, the average value will be closer to the finished total. When the bulk of the labor is added in the finishing operations, the average value of work-in-process is close to the material value. For most manufactured parts, all material is committed when the lot is started.

Subassemblies and assemblies may have some components added in later assembly operations; this would materially affect the average value of work-in-process only for long assembly cycles, however, where all parts for the assembly were not drawn from stores and issued together.

DISCRETE LOT-SIZING TECHNIQUES

The planning techniques so far discussed for lot-size inventories have used the familiar square-root formula for EOQ. This assumes that the usage is uniform and the average lot-size inventory is one-half the order quantity. Components of assemblies and raw material for manufactured parts produced in lots ***are not used at a uniform rate,*** and discrete lot-sizing techniques (9) have been developed for these. They are based, the same as the square root approach, on the assumption that the total costs will be lowest when ordering costs and carrying costs are equal.

Studies are underway to evaluate the error involved in using the square root calculation when planning total lot-size inventories for families of items although discrete techniques are used in the actual ordering. It is already clear that this error is small compared to the benefits achieved. Since one-year planning horizons are typical of computerized material requirements plans, computer programs can be developed to get better answers by simulating aggregate lot-size inventory investment vs. operating expenses based on the specific discrete lot-sizing techniques used. Wagner/Whitin (11) have developed an algorithm which spans the full planning horizon using an Order Point/Order Quantity system. It has been shown to yield some economies compared to fixed order points and order quantities but has not been tested against discrete lot-sizing in a material requirements plan.

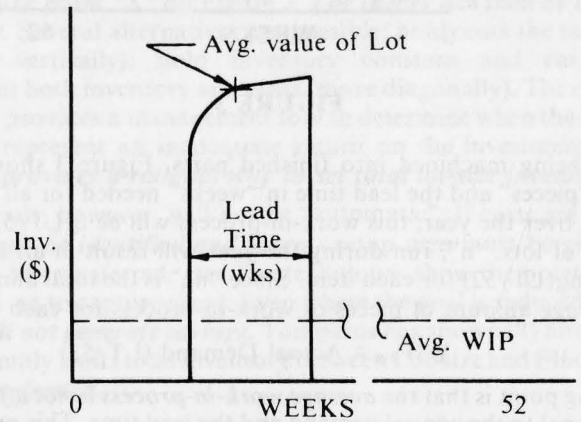

FIGURE 4

DEMAND-FLUCTUATION INVENTORIES

These inventories (usually called "safety stocks") are established by the timing of replenishment material arriving in stores. If replenishment lots are received sooner, larger balances of inventory will be found still on hand and vice versa. There are two basic methods of determining ***when*** to place replenishment orders; the Order Point/Order Quantity system and Material Requirements Planning. In 1965 Dr. J.A. Orlicky of IBM stated the Independent/Dependent Demand Principle, an important guide for practitioners in selecting which basic system to use. He defined independent demand as "demand unrelated to demand for other items"; hence it must be ***forecast.*** Dependent demand is defined as that "resulting from demand for other items";

therefore, it can be ***calculated*** from the higher level demand. Typical of independent demand are customer orders for stocked finished products or spare parts; such demand obviously must be forecast. Components of assemblies, semi-finished parts and raw materials are dependent demand items and their requirements can be calculated by "exploding" the bill of materials for the finished product. The ***Order Point/Order Quantity system*** should be used with ***independent demand items*** and ***Material Requirements Planning*** with ***dependent.***

Probability theory and statistical analysis have been applied in a variety of ways to Order Point/Order Quantity systems to determine the amount of fluctuation inventory needed to support a specific level of customer service. In 1934, R.H. Wilson of the Bell Laboratories published the first article (12) describing one technique. Since then, literally thousands of articles and books have been written on the "scientific" determination of Order Points to provide reasonable assurance of achieving a given level of customer service. Where properly applied to independent demand items, these have helped achieve significant benefits. Used on dependent demand items, however, they have usually generated excessive inventories and distorted priorities.

Applying one of these techniques, Table 4 shows the relation between fluctuation inventory and backorders for a bearing with very stable demand. A good weekly forecast has held the error about equal to one-day's average usage. The safety stocks have been calculated using a measure of customer service defined (13) as "percent of demand filled routinely from stock without backorders". If no safety stock were carried backorders would total almost a month's demand (7,850 pieces), probably occurring periodically in small amounts throughout the year. Required safety stocks increase faster as the tolerated level of backorders decreases. To reduce backorders by about 4,700 pieces requires approximately 1,500 more units in safety stock, but a further reduction of only 1,000 pieces in the backorder total requires an additional 1,400 pieces in safety stock. Theoretically it would require an infinite amount of inventory to insure "no backorders"; actually the maximum demands experienced on this item indicate that about 6,250 pieces would prevent backorders with only rare exceptions.

TABLE 4

Bearing BJ4726
Forecast = 2250/week
Average Forecast Error = 450
Order Quantity = 9,000
Lead Time = 4 weeks

Maximum Quantity Backorders per Year	Demand-Fluctuation Inventory	
	Pieces	Days Supply
7,850	0	0
5,850	360	0.8
1,170	1,800	4
120	3,240	7
10	4,440	10
0	6,250	14*

*Theoretically "infinite"

Some companies, particularly those in the distribution or retail business like to measure customer service this way. Other companies are less interested in ***how far*** out of stock an item may go and are more concerned about the ***frequency*** of its going out.

They use a customer service measure defined as the percentage of times an item is "exposed" to a stockout that it does ***not*** stockout. An item ordered ten times a year will have ten "exposures" just before being replenished because its inventory is then at its lowest ebb and there is maximum danger of stocking out. A "90% service" requirement would aim for only one stockout per year, nine exposures out of ten without a stockout.

Many other measures of customer service may be of interest to particular companies but rigorous statistical calculations have been developed only for backorder and stockout measures. These methods give the appearance of great precision but the assumptions on which they are based make the results far from precise. If significant real benefits are to be obtained, these assumptions should be thoroughly understood and the techniques applied with judgment and consideration of their ***total*** impact. Properly applied, however, they can be most effective in putting fluctuation inventories where they will do the most good — get the best service for the least investment, far better than rules-of-thumb like "one week's supply of safety stock on all items".

TABLE 5

Item	Average Weekly Demand	Order Quantity	One Week's Supply Fluct. Invent.	One Week's Supply Stock Outs	Statistical Fluct. Invent.	Statistical Stock Outs
A	500	500	500	2	460	2
B	500	500	500	9	965	2
C	500	6,500	500	0	0	2
Totals			1,500	11	1,425	6

Table 5 illustrates this point for three items manufactured for stock. Carrying one week's supply as safety stock results in an inventory of 1,500 pieces and 11 stockouts per year. The table shows how statistical techniques could be applied to keep the fluctuation inventory total about the same but reduce the number of stockouts from 11 to 6. Also, stockouts are now evenly distributed among the items instead of being concentrated on one. ***When fluctuation inventory is spread evenly, stockouts are not.***

In this example, Item C needs no safety stock if two stockouts are tolerable because it is exposed to stockout (ordered) only four times a year. Without safety stock it would probably go out of stock only twice; by the "law of averages" the actual demand will exceed the forecast only half the time. Item B needs more than twice as much safety stock as Item A since its demand variations are considerably greater. ***The statistical approach puts the safety stock where it is needed to get equal service on all items.*** Note that the service level on Item A remains the same, is very significantly improved on Item B but is poorer on Item C. Several alternatives are available to the inventory manager. He may decide to keep some inventory on Item C to avoid making its situation worse and improve Item B as much as possible with the balance of inventory available. He can aim for a smaller improvement in customer service and also reduce the total safety stock, splitting the benefits.

Using statistical methods for determination of fluctuation inventories, a "trade-off curve", Figure 5, can be drawn for families of items. This shows the relationship between inventory and customer service and has the same general shape as the lot-size inventory curve, Figure 2. The amount of inventory increases dramatically as the customer service level approaches perfection. This is shown also by the data in Table 4.

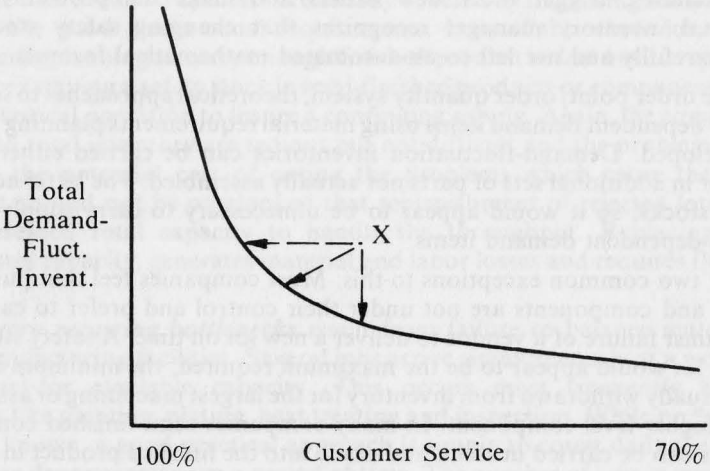

FIGURE 5

Rules-of-thumb, intuitive approaches or other non-rational methods of establishing safety stocks usually result in "off the curve" performance, point "X" — too much inventory is carried for the service level actually achieved. Aplication of the theory permits getting down on the curve, either by holding service level constant and reducing inventory, holding inventory constant and improving service or some combination of both. The technique also gives data needed to evaluate the "return on investment" to move from one point on the curve to another. Return is expressed in terms of improved customer service and not in dollars. Improved customer service will usually generate some benefits in increased sales, fewer substitutions of higher cost products or reduced expenses in freight, handling backorders, answering customers complaints, expediting, etc. The most important payback will usually be increased sales and the determination of the proper customer service level must be a manager's judgment based upon estimates of how sales might be improved. ***There is no way to calculate where is the "right" point to be on the curve.*** However, the trade-off curve technique does provide quantitative data for decision making, putting in perspective the investment implications of policies like, "We can't afford to ever be out of stock" and other beautiful generalities.

SUPPLY-FLUCTUATION INVENTORIES

Uncertainty of supply affects both independent and dependent demand items. Variations in replenishment lead time probably cause more stockouts, backorders and missed delivery dates than fluctuations in demand. Theoretical approaches to combining the effects of both demand and lead time variations in calculating order points have been developed (9) but are rarely used. Raising order points to provide more safety stock as lead times get longer aggravates the basic cause of the longer lead times — higher levels of work-in-process. True control of lead time requires regulating work input rates to match available capacity and to provide a balanced flow of work through manufacturing facilities. (10)

This basic input/output principle applies equally well to purchased materials. (14) Falldowns in vendor deliveries are caused more frequently than is recognized by the customers' poor ordering practices. "Dynamic order points" would react to such

delivery failures, trigger more new orders and make the problem worse. The professional inventory manager recognizes that changing safety stock must be handled carefully and not left to an automated mathematical formula.

Unlike the order point/order quantity system, theoretical approaches to setting safety stocks for dependent demand items using material requirements planning have not yet been developed. Demand-fluctuation inventories can be carried either in finished product or in additional sets of parts not actually assembled. The latter act effectively as safety stocks, so it would appear to be unnecessary to carry supply-fluctuation stocks on dependent demand items.

There are two common exceptions to this. Most companies feel that purchased raw materials and components are not under their control and prefer to carry stock to guard against failure of a vendor to deliver a new lot on time. A safety stock equal to one extra lot would appear to be the maximum required; the minimum might be the amount usually withdrawn from inventory for the largest machining or assembly lot of the next higher level component. In many companies semi-finished components or assemblies can be carried in stock and made into the finished product in a very short time. There may be relatively few varieties of semi-finished components assembled into a large number of finished products so the most flexible inventories are the components. Mechanics and carpenters hand tools held in bulk inventories but sold in mixed sets are a good example of this situation. Carrying safety stocks at this level results in very much lower total fluctuation inventories since the total demand variation is likely to be much smaller than the sum of the demand variations of the individual finished items. Attempts have been made to apply rigorous statistical techniques to determining the needed amounts of fluctuation inventory for such items but so far without much success. The difficulty stems from determining what is the "forecast error" and defining "customer service" for this situation. Carrying safety stocks only at the high and low levels implies good control over processing lead times which requires sound capacity planning, good work-input control and effective shop floor control with a dynamic priority technique to keep the system responsive to the inevitable changes.

Within a manufacturing plant there are several basic causes of failure of supply, each requiring its own method of evaluating the needed amount of fluctuation inventories to give a desired level of protection.

Machine breakdowns, equipment malfunctions or tool failures require inventories to prevent down-time. Manufacturing people know that some work-in-process is needed to keep people and machines busy when operations that feed them stop. Most plants count on high levels of work-in-process to provide this kind of insurance automatically but it doesn't. Just having plenty doesn't provide the right items. If machines break down frequently, tooling is cranky or people can't consistently produce good quality, work-in-process inventory should be planned to keep subsequent operations busy. Pick active items, with plenty of work-content for the operations to be fed, hold one lot or enough to make up for the interruption. The investment in this insurance can be evaluated; if it's high enough it can help focus attention on solving the real problems. Again, it's a question of having return on investment data to help make better decisions. While such calculations may be tedious they are not difficult. The problem is deciding how much it will cost in improved preventive maintenance programs and better designed tooling to prevent the breakdowns and make the inventory unnecessary.

Quality rejections can result in small scrap losses or even unexpected loss of whole lots, typical of pharmaceutical production, food processing, heat treating, ceramic

firing and the like. Small scrap losses are usually covered by increasing the starting lot-size so that the good pieces equal requirements. Loss of the whole lot, however, requires specific planning to carry enough finished product to last until a replacement lot is made or carrying a safety stock in semi-finished products or components already through the critical operation to insure a continuing supply. Again, the computations of the needed total inventory are tedious but not difficult and the problem is one of determining the potential cost of curing the problems which cause the periodic rejections. It should not be overlooked that replenishment of rejected lots actually requires increased total capacity to handle the throughput. Replacing rejected material wastes capacity, generates material and labor losses and requires fluctuation inventory.

Temporary recurring bottlenecks result from failure to balance material flow through manufacturing facilities. Several jobs arrive simultaneously at a work center and compete for available capacity. This occurs most frequently at service departments like painting, plating, heat treating and inspection. While no "scientific" approach is known, a good practical approach is simply to count daily the backlogs ahead of these departments over a period of time. The number of jobs in queue will be found to vary from a lower to an upper limit, say from 5 to 15. Obviously the facility could operate just as well ***without the minimum quantity*** of 5 jobs in the queue since it is always there. Work-in-process levels could then be reduced by 5 jobs with danger of only occasional downtime. The range would be 0-10 and the average level 5 jobs ***even if control of flow weren't improved.*** Such determinations can be made easily for critical areas where large bottlenecks occur frequently.

Strikes or threats of strikes at vendors' plants, by truckers or on railroads require planned increases in inventories to insure supply during the strike. Potential strikes within a plant may cause similar inventory buildups. Most trade journals carry information on important labor contract expiration dates so that the timing of buildups can be determined early in the year. Such inventories usually represent a very substantial investment. Deciding to carry them assumes it is more expensive to shut the operation down, let customers wait or work on alternate materials in the interim. Determination of the investment in fluctuation inventory is simple. The return on this investment is rarely considered. Because of the impact not only on a company's economic health but on our overall economy such decisions should be much more carefully considered than they usually are.

ANTICIPATION INVENTORY

Peaks and valleys in sales demand are caused by seasonal products, sales promotions and selling price changes. There are significant savings to be made by carrying anticipation inventory to level out production in spite of such swings. Anticipation inventory is needed also to cover interruptions in production from relocating or replacing machinery, vacation shutdowns or moving departments or plants. The savings are in two classes: lower investment in plant and equipment compared to having capacity to meet peak loads and reduced costs such as hiring, layoff, training, overtime, downtime, scrap and rework. As usual these costs are not detailed in standard accounts but must be "engineered". The inventory required will be the total of all items needed in excess of the capacity of the manufacturing facility.

Techniques for planning capacity to meet peak demands or interruptions in production are well-known (9, 15, 16). Table 6 is typical of plans for a make-to-stock business.

TABLE 6

Week	Sales Week	Sales Cumul.	Production Week	Production Cumul.	Inventory Total
Start		42,000		38,500	15,000
4/7 Plan	3,000	45,000	4,000	42,500	16,000
Act					
4/14 Plan	3,000	48,000	4,000	46,500	17,000
Act					
4/21 Plan	3,000	51,000	4,000	50,500	18,000
Act					
6/23 Plan	3,000	78,000	4,000	86,500	27,000
Act					
6/30 Plan	3,000	81,000	4,000	90,500	28,000
Act					

It shows production rates required to meet forecast shipments and build up the finished goods inventory in anticipation of the annual vacation shutdown in July. The intent is to have total finished goods inventories at the end of the vacation shutdown no lower than the base level (equal to the target lot-size plus demand-fluctuation inventories). At the start of the vacation period, therefore, the inventory would have to be above base level by an amount equal to total shipments during the shutdown. To build up to this figure requires that production be higher than the shipping rate. The amount of the difference, of course, depends on the time available to buildup the inventory. The farther in advance this buildup can be started the less the difference between average and actual production requirements. Ideally such inventory buildup should start at the close of the preceeding vacation. The inventory at the start of the planning period (I_s) plus production (P) during the period minus total shipments (S) will be the inventory at the end of the planning period (I_e). The calculations are very simple:

$$I_s + P - S = I_e$$

This is a basic relationship for total inventories. It shows clearly that ***inventories are really controlled only by balancing production (input) and shipments (output).*** The equation can be used to determine any one variable when the other three are known. For vacation buildups, forecast shipments and the starting and ending inventories would be known, and the calculated production can be spread over the planning period. If production is inadequate to meet shipments, the formula can be used to determine what total inventories will be at the end of the planning period. This can then be compared to target levels for lot-size and fluctuation inventories to determine how customer service and/or operating costs might be affected. The formula can also be used to determine the relationships among inventory, input (P) and output (S) of any manufacturing facility - work centers, departments, plants, etc.

Capacity plans like Table 6 permit setting weekly or monthly total inventory budgets which provide the basis for control of capacity. Comparing actual to planned figures ***for all three variables (shipments, production and inventory) on a single report*** provides all the facts relevant to decisions about whether or not to change production rates. Capacity plans are also an excellent device for comparing alternative strategies for production and inventories. For example, if seasonal shipments are met by level production throughout the year, maximum swings will occur in the inventory. Peak

inventory can be minimized by changing the production rate one or more times during the year; the alternative production rates and inventories can be studied to evaluate costs and benefits.

Inventory investment is easily determined but costs are more difficult. In addition to hiring, layoff and the other factors mentioned, the intangibles of loss of skilled help, reputation as a good place to work and the social responsibilities of business to provide dependable employment must be considered in making production decisions. No formula or technique will make these decisions for management.

For make-to-order businesses, the backlog of orders corresponds to product inventories in make-to-stock companies and a similar equation can be set up:

$$B_s + O - P = B_e$$

The order backlog at the start of the planning period (B_s) plus incoming orders (O) minus shipments (which are equal to production (P) since there is no finished product inventory) will be the resulting backlog at the end of the planning period. Production plans using these relationships can be set up like Table 6 and used for the same purposes of control and decision-making.

The major problem in planning anticipation inventories is the difficulty in forecasting seasonal peaks, the effect of sales promotions and selling price changes, shipments and incoming orders a year in the future. To be most effective, therefore, such plans must be updated regularly as forecasts change or production schedules are missed. Another real problem arises in evaluating actual inventory in fluctuation and anticipation groupings. It is possible to determine the actual value of lot-size inventory on hand. However, total inventory above this amount is combined fluctuation and anticipation classes and there is no way to distinguish between these. All that can be done is to compare actual total of all classes against the plan.

TRANSPORTATION INVENTORY

This classification includes all materials in the market distribution pipeline, intransit and therefore not available to serve the other functions of inventories. There is some minimum in-transit inventory necessary just to keep the operations going. The return on this investment is the value of not shutting down. Calculating how much is a straightforward determination of the number and value of shipments in transit. If the shipping time is two weeks and a truck load worth $40,000 is shipped each week the in-transit inventory will obviously be $80,000. For a given sales rate the only way to reduce this inventory is to reduce the transit time. This usually involves higher freight costs. "Not spending" this money can be viewed as a "return" on the amount of transportation inventory investment above that for the faster shipments.

Rather dramatic reductions in air freight costs in recent years (from 27¢ per ton mile for DC3 flights to an estimated 3 to 5¢ per ton mile for 747 jumbo jets) may make significant decreases in in-transit inventories economical for companies with high-value, low-mass products. Although still considerably more expensive than truck, rail and boat rates, air freight makes possible lower inventories from reduced in-transit and smaller safety stocks; the "return" generated by using the cheaper shipping methods could be too little payback on the extra inventories necessary. An additional factor is the potential reduction in accounts receivable. One machine tool company recently flew a large piece of equipment worth $280,000 across the ocean. Bringing the cash into their operations several weeks earlier was a major factor in their decision.

Planning and controlling all classes of inventories in branch warehouses should be based on determining the economic frequency of shipment (9). This aims for the

minimum total of ordering, shipping and inventory carrying costs. The total lot-size inventory will be set by the shipping frequency and standard statistical analyses used for setting total safety stocks. Adding warehouses will require not only more in-transit material but also more fluctuation inventories to maintain the same customer service levels. A formula is available (17) to approximate the amount of safety stock needed in each of "n" warehouse locations compared to a single location:

$$SS \text{ (one branch)} = SS \text{ (single location)}/\sqrt{n}$$

HEDGE INVENTORIES

Companies using large quantities of basic minerals like silver and copper or of commodities like wool, grains, etc., can make significant savings by buying extra quantities when prices are low. Also extra quantities of purchased items brought into inventory in advance of a price increase will reduce the total cost of these items. These savings are obviously the return on the added inventory investment. For both these examples, the quantity to be purchased should be determined by the potential return on the investment modified, of course, by such factors as available capital, product shelf-life and potential design obsolescence.

ANSWERING THE BASIC QUESTIONS

Too few companies are enjoying real benefits from "scientific" inventory planning techniques. Understanding proper use of the trade-off analyses presented here, a few professional practitioners are able to give quantitative, rational answers to the basic questions of inventory management.

"How should inventory vary with sales?"

The answer is obvious when the functional classifications are studied individually. Lot-size inventory should increase or decrease approximately ***as the square-root*** of sales. Doubling sales requires only forty percent more inventory to keep total costs minimized. This is self-evident when the familiar square-root formula is used for setting order quantities. It seems likely that discrete lot-sizing techniques produce similar results but this is yet to be proved. The work-in-process fraction of lot-size inventory has already been shown to vary directly with sales (p. 8).

The way demand-fluctuation inventories change with sales rates depends on how forecast accuracy is affected. If increased sales result from selling more of the same things, demand variations usually decrease, meaning that forecasts are closer to actual demand. Safety stocks to maintain a given customer service level will not increase proportionately to sales; in many cases they can be held at the same level and sometimes even reduced. When higher sales are generated by adding entirely new products or more models of existing lines, demand-fluctuation inventories will frequently have to be raised well above proportionate levels. New products are the most difficult to forecast and, hence, errors are large.

Supply-fluctuation inventories apparently bear no rational relationship to sales rates. A good practical approach would seem to be to hold target levels the same for small ($\pm$ 20%) changes in sales rates and change them only for larger swings. Since few companies experience growth-rates or cutbacks in excess of 20%, this factor can often be neglected. Anticipation, transportation and hedge inventories will all have to vary directly and proportionately to sales rates since all involve "time-periods of supply".

An awareness of these relationships makes it possible for the professional to adjust budgeted inventories for varying forecasts of sales demand on a rational basis ***working with the functional classes.*** Translating into the traditional accounting groupings

requires tedious but not difficult calculations. It's a good question if it is really worth the effort.

> ***"What will happen to customer service and to operating costs when inventory levels are changed?"***

This can be answered through the development of trade-off curves like Figures 2 and 5. The Stanley Works, Fafnir Bearing, McGill Manufacturing, Black & Decker and other companies have used the aggregate lot-size approaches discussed here to develop inventory investment vs. operating cost data. Order quantities will then be consistent with real-life limitations on setup or equipment capacity. New dimensions can also be added to capital equipment justification analyses when inventory investment changes can be evaluated.

A very simple approach used by many companies for deciding how low work-in-process can be dropped before down-time costs are affected is to watch the "queues" of work in major work centers and keep reducing these backlogs until they occasionally drop near zero. This generates many fringe benefits beyond reduced inventory. It focuses attention on smoothing out the flow of work so the plant can run with lower work-in-process and few interruptions. It produces shorter and more dependable lead times which lead directly to improved customer service. It's well worth the extra management effort required.

Fewer companies have used customer service vs. investment trade-off curves, but those who did gained considerable insight into sales policy implications and saw real improvement in working relations between marketing and manufacturing people. Probably the greatest benefits have come to those who used the approach to improve ***both*** service and investment. You can't do better than making both the controller and sales manager happier.

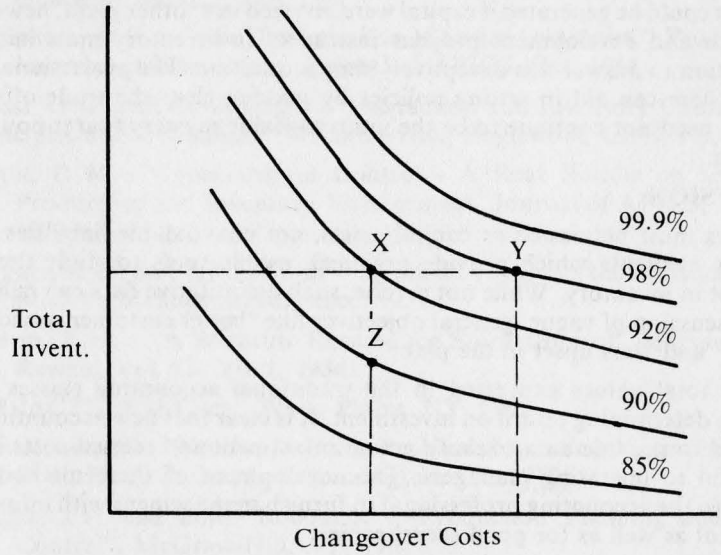

FIGURE 6

Probably the most interesting application of the total approach was developed at Fiber Industries, Inc., Salisbury, North Carolina. This plant manufactures synthetic staple fibers to stock and incurs very heavy change-over costs on equipment which usually runs near full capacity. Applying both statistical safety stock and economic

lot-sizing techniques, their computer program provides data to permit them to draw curves like Figure 6, showing inventory vs. changeover cost for a range of customer service levels. With these data, updated weekly, management is able to study a wide variety of alternatives.

For example, if total inventory is to be kept at the present level ("X"), the curves show how much operating costs will increase to achieve a given improvement in service (move to "Y"). They also show how service will be affected if inventory is to be reduced and operating costs held constant (move to "Z"). Management can see the alternatives of the various courses of action available and the trade-offs involved.

In one company the traffic manager investigated alternate shipping costs from the East to the West coasts and estimated that annual freight expense could be reduced about $50,000 using boat shipments via the Panama Canal instead of direct rail. The production control manager pointed out that the increased transit time would result in seven times as much inventory in transit. In addition, longer lead times would require almost four times as much safety stock in the West coast warehouse to maintain the same level of customer service. The $50,000 annual freight savings represented an inadequate return on the added capital investment in transportation and the company continued shipping by rail.

"How much inventory is enough?"

There is no straightforward, fixed answer to this. ***It is really dependent on management's policies.*** What change do they want in customer service? What increases in costs will they accept to reduce the total investment in inventories? What are their policies regarding market distribution and warehousing? These and other questions relating to inventories will determine how much inventory is required. Equally important are alternate uses of capital and the return they can generate. The return that could be generated if capital were invested in another plant, new equipment or research and development projects instead of in inventory must be taken into consideration to answer this deceptively simple question. The professional approach described here can aid in setting policies by making clear the trade-offs involved. Inventory need not continue to be the unmanageable mystery that it now is in most companies.

CONCLUSION

Inventories must be viewed as capital assets, not unavoidable liabilities. There are techniques available which provide practical. usable tools to study the return on investment in inventory. While not precise, such quantitative data can help eliminate useless discussion of vague, general objectives like "better customer service", "higher turn-over" and "less upset in the plant".

Inventory total values expressed in the traditional accounting classes contribute nothing to determining return on investment. It is clear that new accounting methods are needed to provide data on both actual investment and related costs in the form most useful to operating managers. The development of these methods is a real challenge to the accounting professional to furnish management with information for true control as well as for good scorekeeping.

The ***functions of inventory which generate savings*** must be studied to see how available techniques can be applied to produce tangible benefits in lower costs, smaller inventories or both. Without changing total inventories, theoretical techniques can be used to ***put inventory where it does the most good.*** Contrasted to intuitive rule-of-thumb approaches, application of the theory permits "getting down on the optimum curve" and generating the highest possible return on inventory investment at that level.

These techniques can then be applied to determine the return on investment implications of moving from one point on the trade-off curve to another. This permits quantifying the relationships between increased inventories and reduced costs or improved customer service to give real facts in familiar terms to managers making operating decisions. The alternate, overworked approach of trying to find the "right" formulas and "magic numbers" to put in them ***to make the*** decision for the manager has not worked and will not. The effects on the strength of a company are too important to trust inventory decisions to machines using automatic rules. Systems must be developed to provide men called managers with data for decision-making.

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